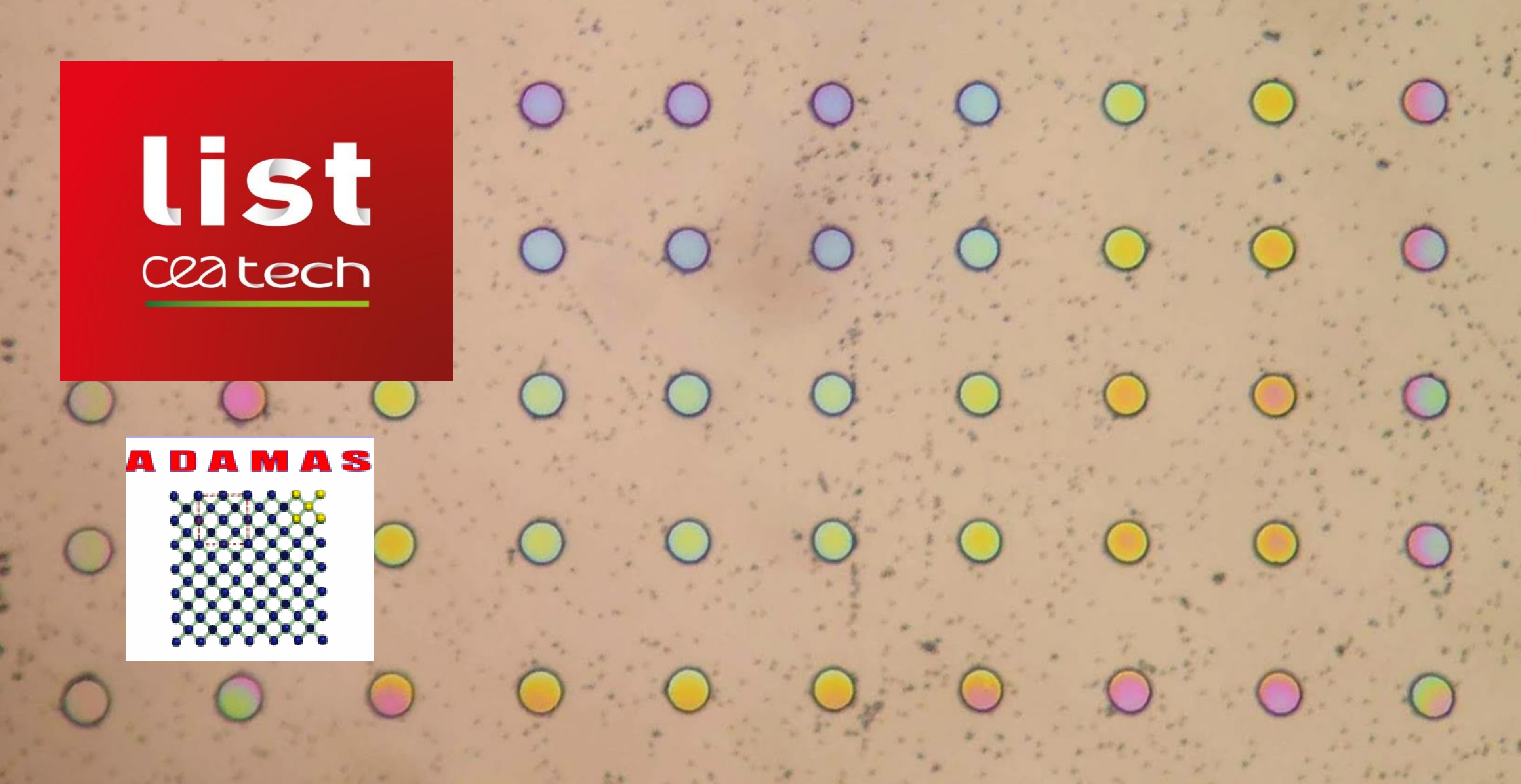


UPDATE ON DIAMOND BASED MICRODOSIMETRY IN HADRONTHERAPY

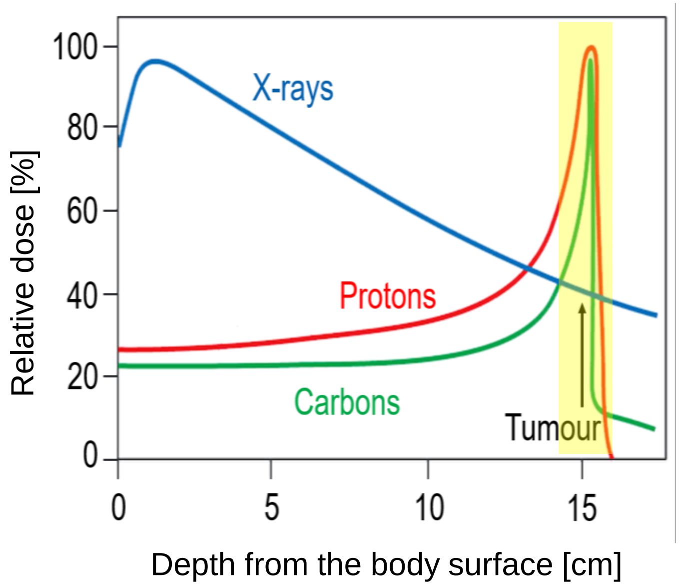
Michal Pomorski et al,CEA-LIST Diamond Sensors Laboratory

8th ADAMAS Workshop ,GSI Darmstadt, Germany, 09-10th December 2019

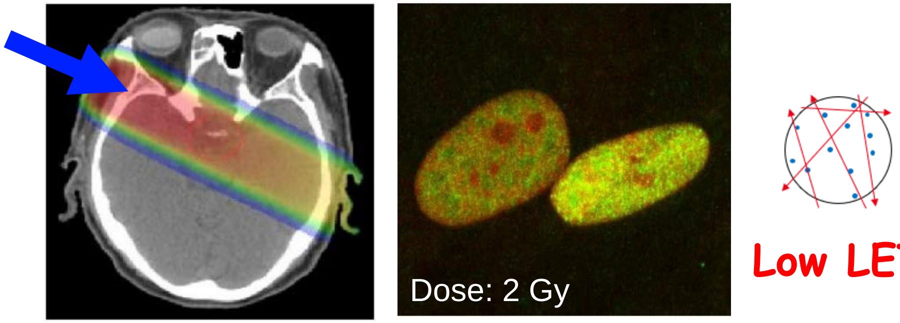
Outline

- **Introduction and motivation**
- **Diamond membrane microdosimeter prototypes and performance**
- **Readout and DAQ**
- **Clinical beamtimes and simulations**
- **What next**

HADRONTHERAPY



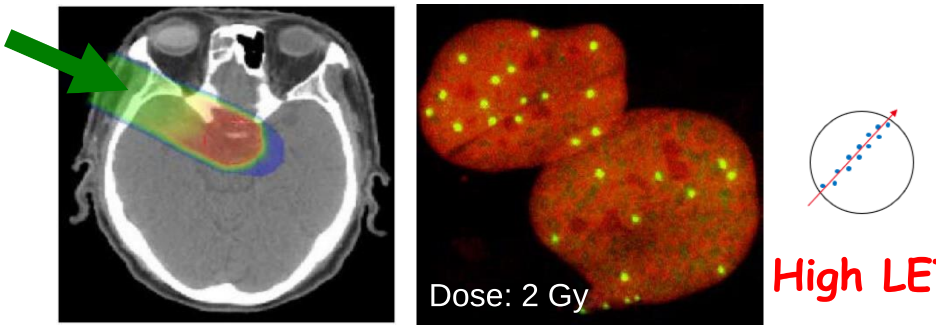
Photons *(SPARSELY ionizing radiation)*



Low LET

[A. Rosenfeld]

Ions *(DENSELY ionizing radiation)*



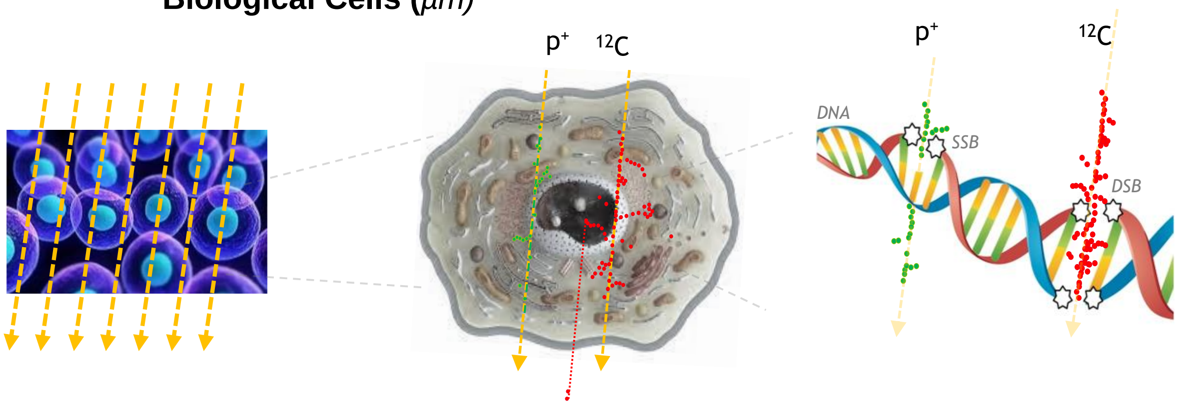
High LET

[A. Rosenfeld]

Same Dose but different (Relative) Biological Effectiveness (RBE)

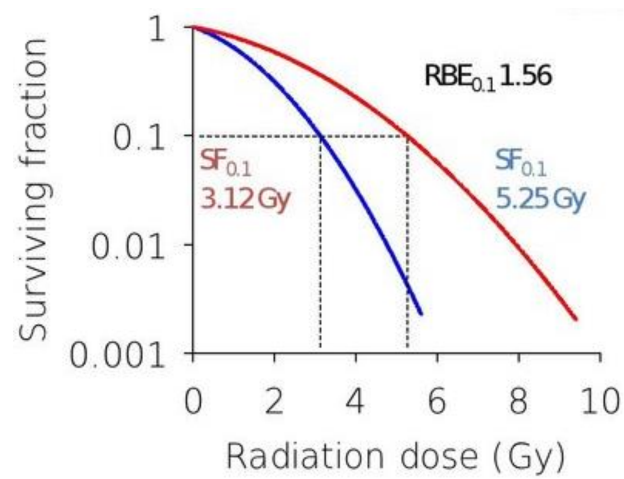
RELATIVE BIOLOGICAL EFFACTIVENES

Biological Cells *(µm)*



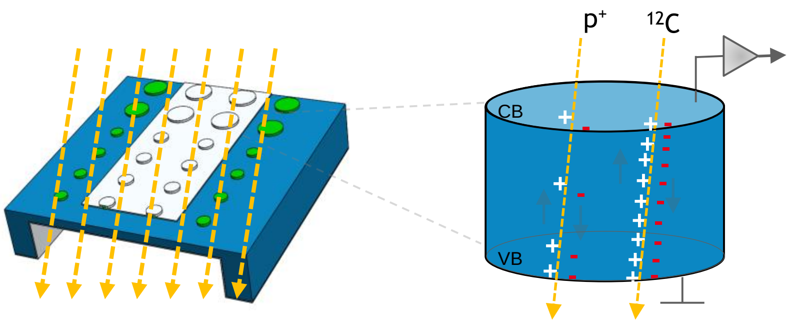
direct

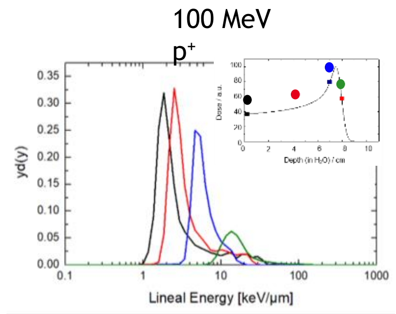
RBE



Micro-Sensitive-Volumes(µSVs)
in microdosimeter *(µm)*

LET

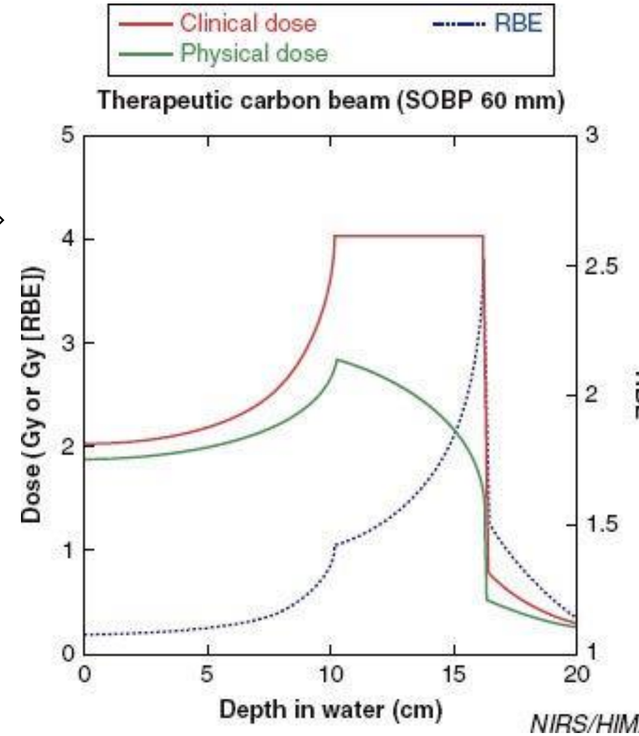




model

MICRODOSIMETRY

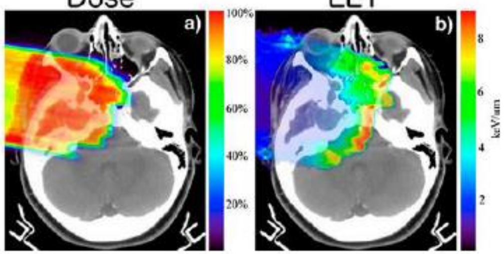
RBE weighted treatment plan is standard for **C therapy**
(13 centres in the world)

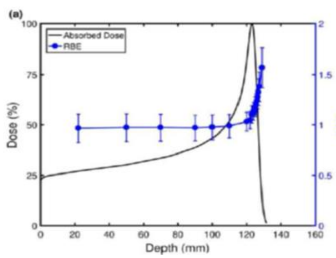


NIRS/HIMAC

For instance **RBE (1.1) effect neglected in proton therapy**
(>100 centres in the world, 3 in France)

Dose LET





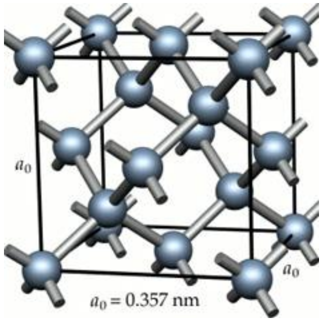
Problems: necrosis of healthy tissue, secondary cancer

2020 → First RBE weighted treatment plans planned for p in France (IC-CPO)

Need for reliable, radiation hard, high spatial resolution, microdosimetric system - commercial systems does not exists

*R&D on microdosmietric systems is ongoing – miniTEPC, Silicon, **Diamond***

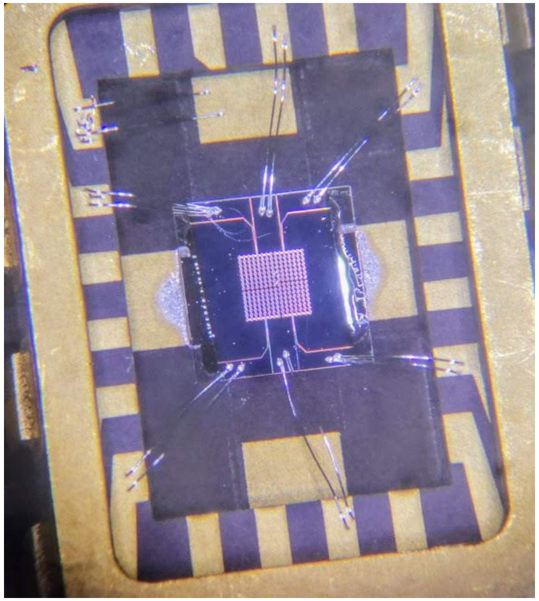
ADVENTAGES OF DIAMOND



Large band-gap (5.5eV) semiconductor

A solid-state ionization chamber
(soon a proportional chamber(?))

more tissue equivalent (Z=6) and radiation hard (43 eV)



+ no leakage current and no need for p-n junction
+ fast drift velocity for e-h
+ low capacitance
+ high electrical breakdown (> 1000 V/µm)
+ VIS light and temp. insensitivity

- high ~13 e-h/eV – lower signal
- it's diamond (for instance pls. forget 6' wafers)

since 2002 high purity electronic grade CVD diamond available commercially
Nowadays 'boom' of man made diamond for jewellery + quantum sensors

CONSORTIUM

CEA partners (PTC-CEA October 2017 → 2020) Health Physics Instrumentation :

DIAμDOS

Diamond-Membrane-Microdosimeter-Collaboration

CEA founded PhD thesis from 2017 (3 years)

Iza Zahradnik

National partners (INSERM November 2018 → 2020):

DIADEM

Diamond membrane based microdosimetric system for radiation quality assurance in hadron therapy

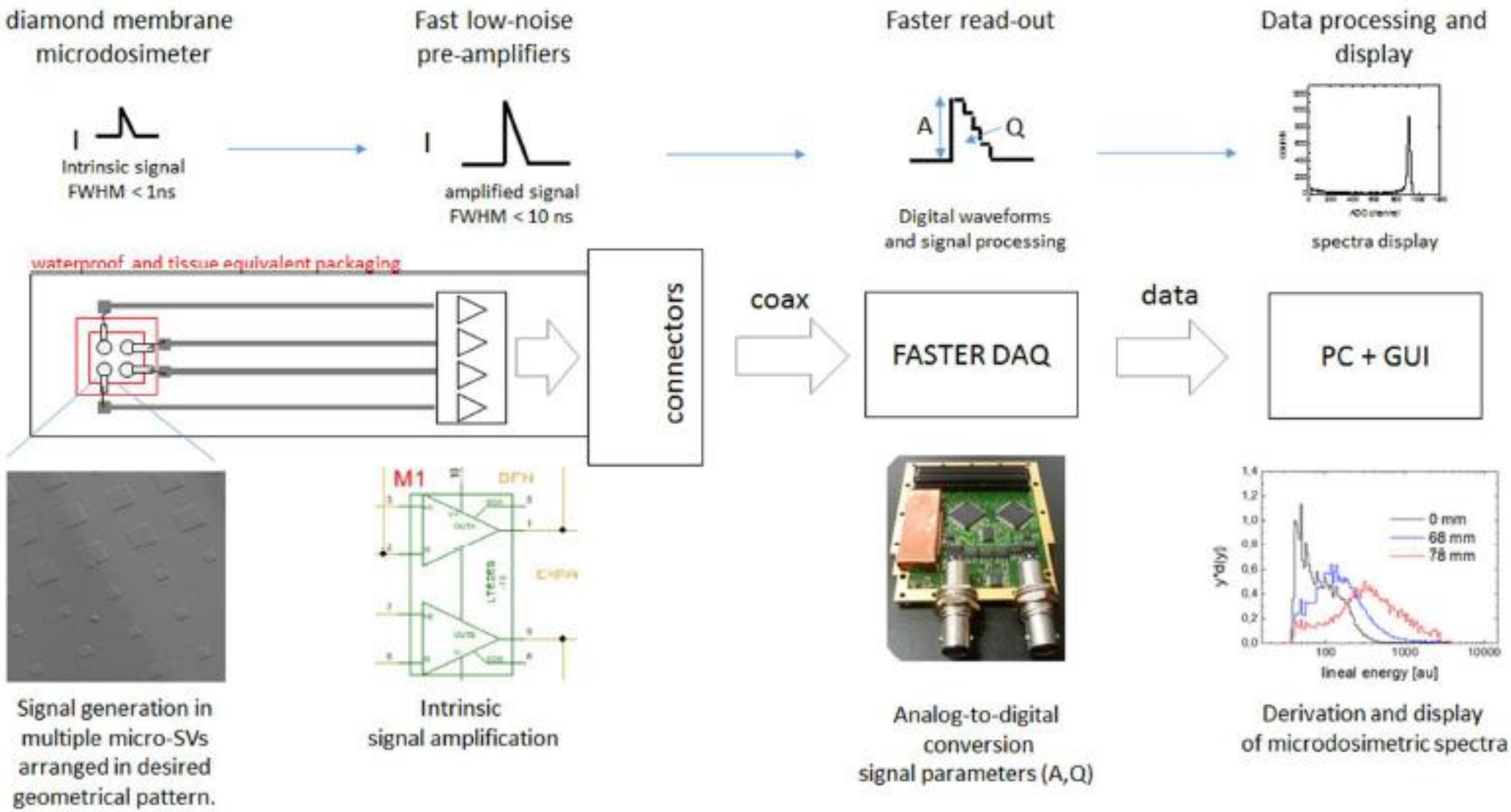
Diamond **mem**brane based microdosimetric **system** for radiation quality assurance in hadron therapy

INSERM founded PostDoc from 2020 (1 year)

Sayo Loto

International partners:

MICRODOSIMETRIC SYSTEM

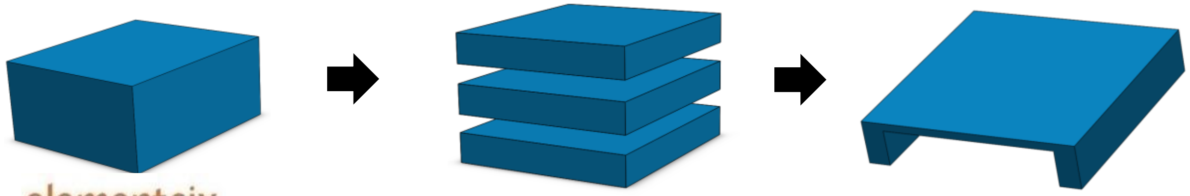


DIAMOND MEMBRANES

Free standing scCVD diamond membranes

Commercial scCVD samples | **Laser slicing&polishing** | **Ar/O_2 deep etching**

Thickness: 300 – 500 µm | 30 – 60 µm | 2-10 µm

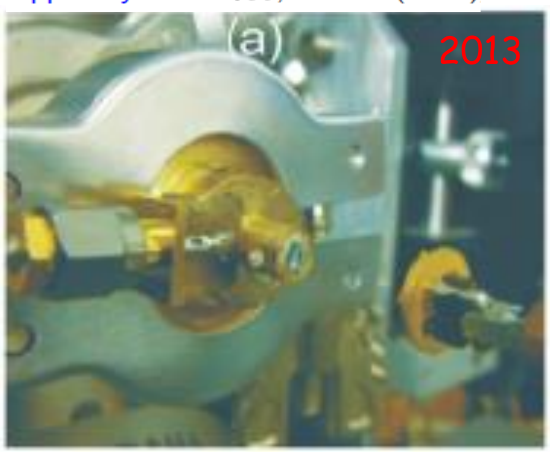


elementsix | Almax·easyLab science under pressure

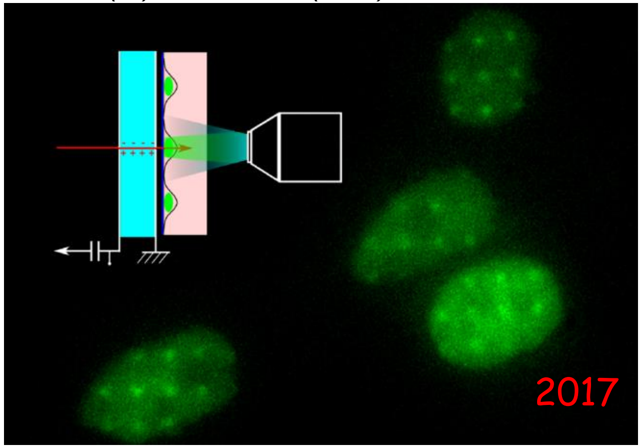
M. Pomorski et al., *Appl. Phys. Lett.* 103, 112106, **2013**

Solid-state 'active' vacuum window ionization chamber for external micro beams

Appl. Phys. Lett. **103**, 243106 (2013)

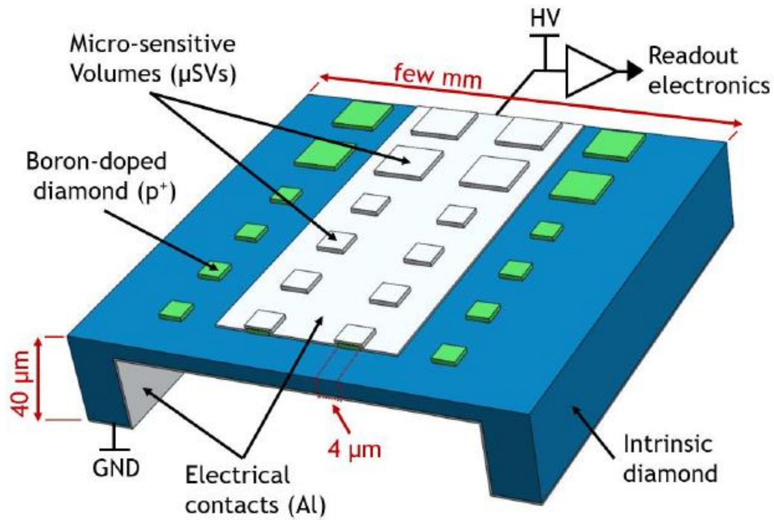


APL 111 (24),243701, 2017 (cover)

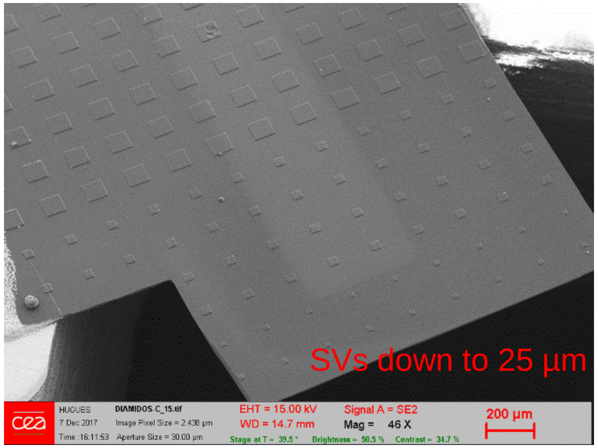


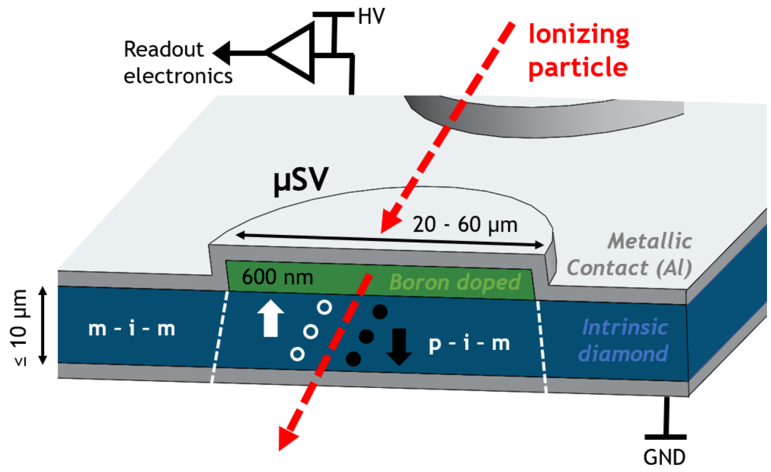
P+ SENSOR

scCVD diamond membrane DIAµDOS p+ microdosimeter fabrication:

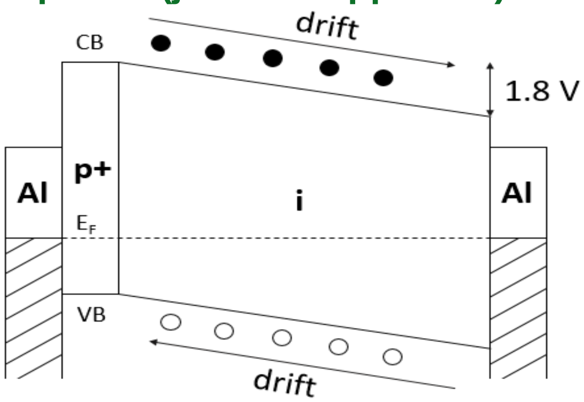


SEM Image





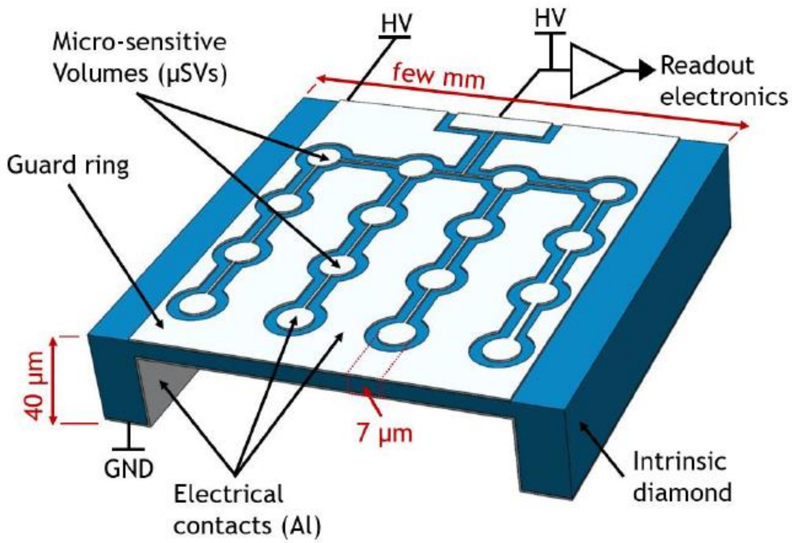
p+-i-m (junction approach)



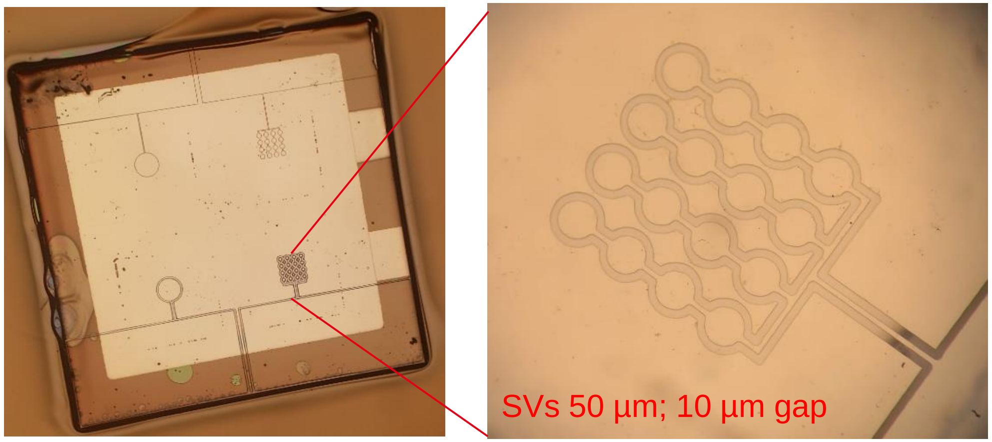
Self-biased bias, fully depleted

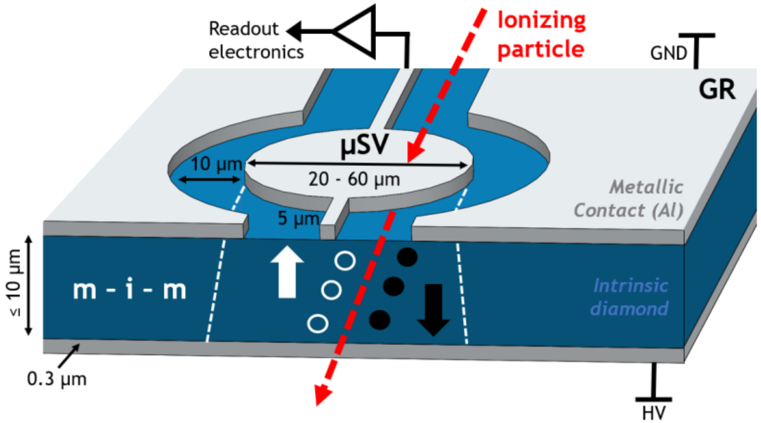
GUARD-RING (GR) SENSOR

scCVD diamond membrane DIAμDOS guard- ring microdosimeter:

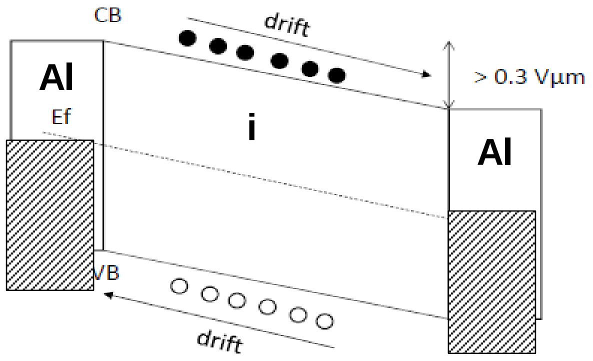


Microscopic Image



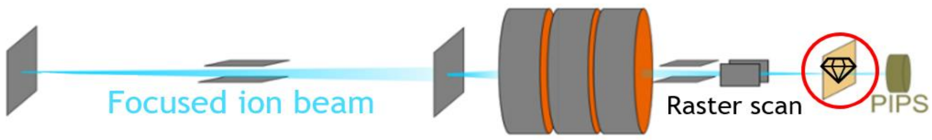


m-i-m (ionization chamber approach)

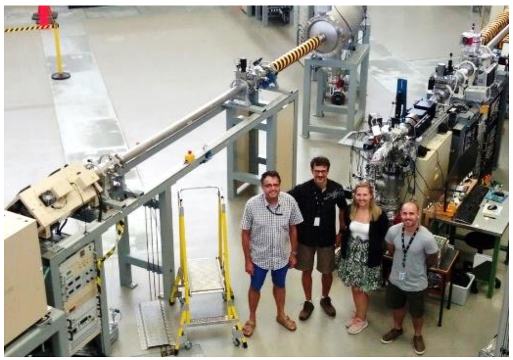


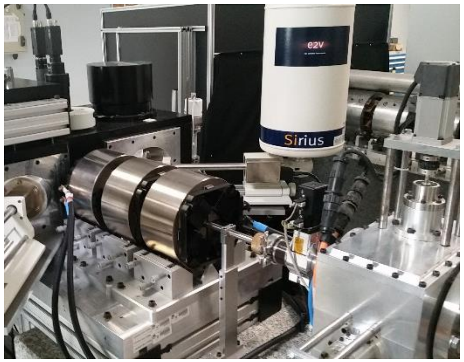
ION BEAM INDUCED CURRENT

IBIC (Ion Beams Induced Current):



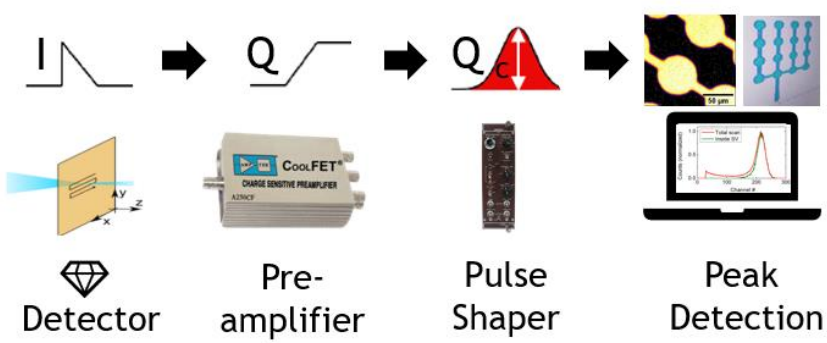
- Single ion irradiation (precision: 1 micron)
- Raster scanning + pulse height spectra
- Charge transport maps (µSV definition)
- Well controlled projectile Energy and LET





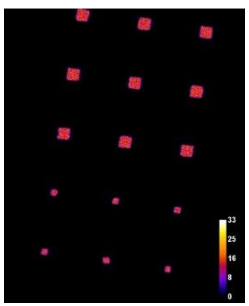
Perfect tool to test new types of microdosimeters before implementing in clinical conditions

Readout:

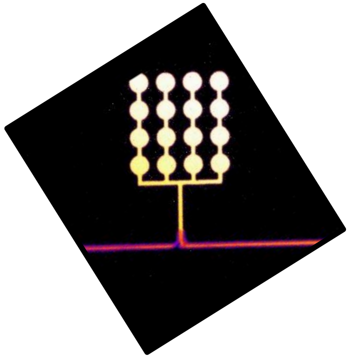


IBIC global response of diamond

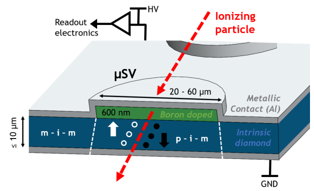
P+

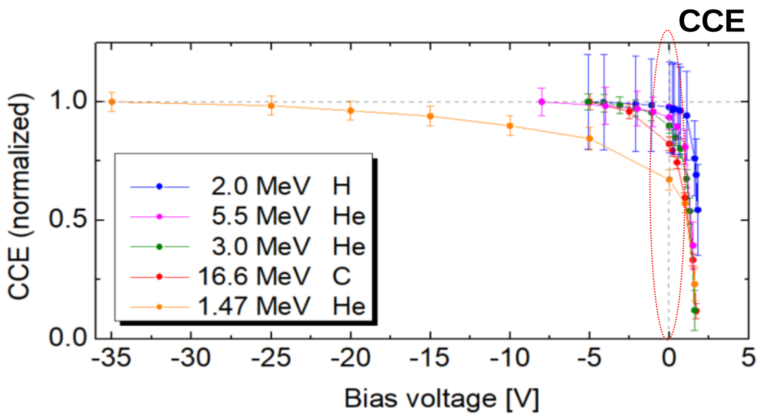


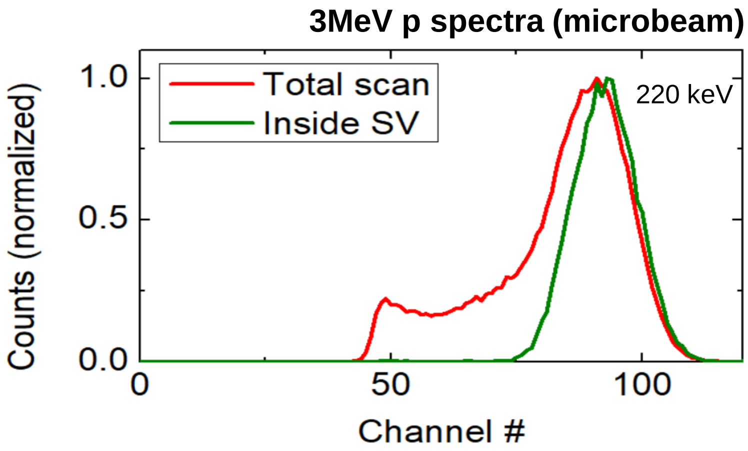
GR



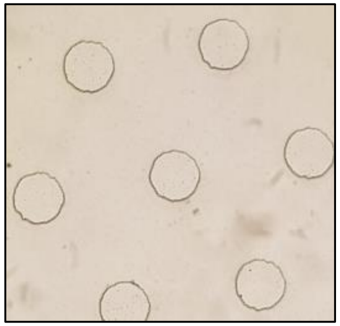
P+ SENSOR PERFORMANCE



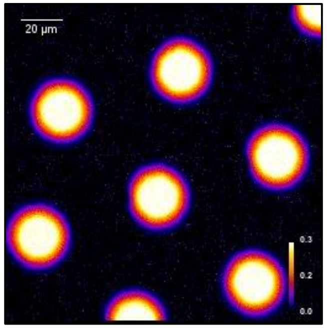




Microsc. Image

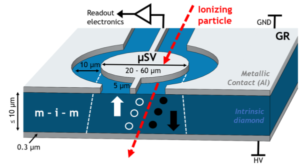


IBIC

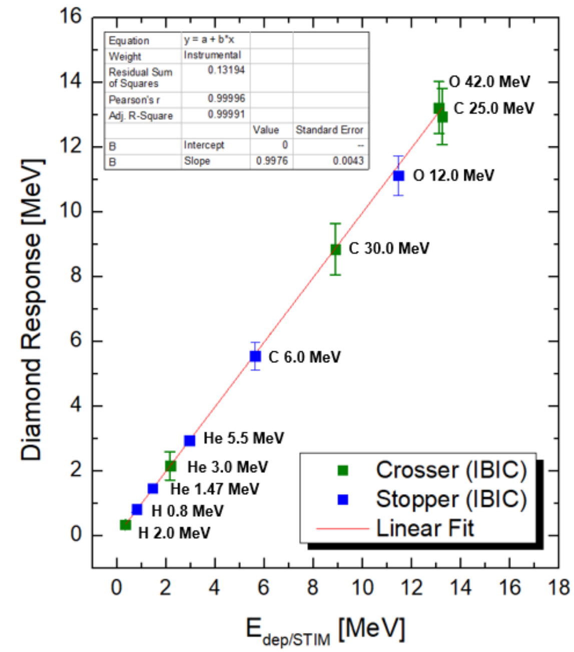


- **self-biased sensor** = no external HV
- low noise = dark current <<1pA
- full CCE for p
- **CCE inefficiency for heavier ions**
- Radhard
- Spectroscopic quality similar to Si

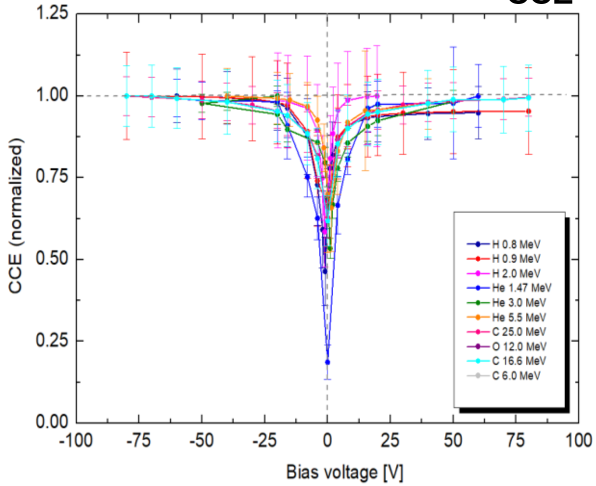
GR SENSOR PERFORMANCE



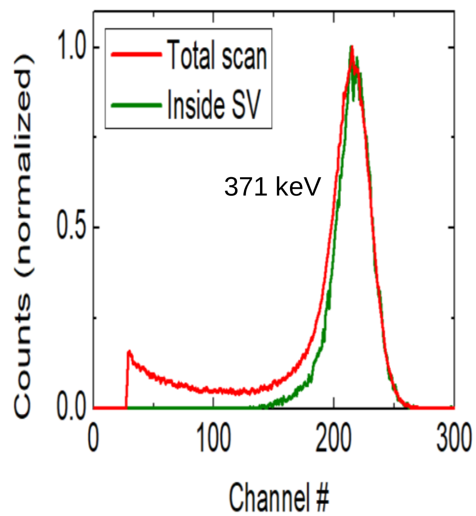
response linearity



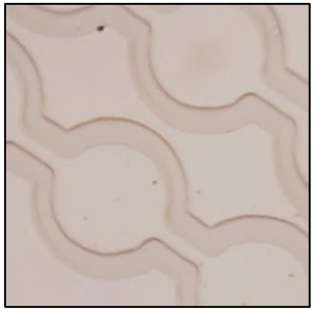
CCE



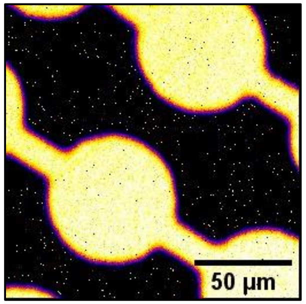
3MeV p spectra (microbeam)



Microsc. Image



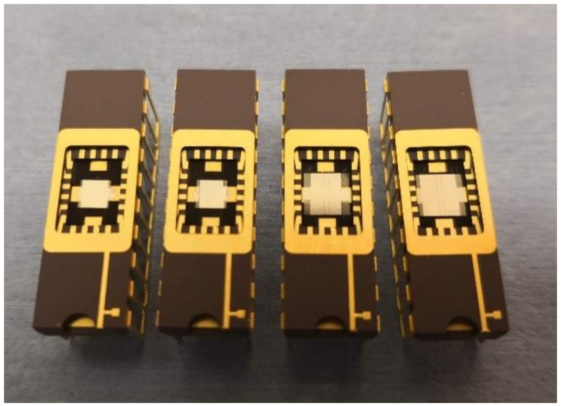
IBIC

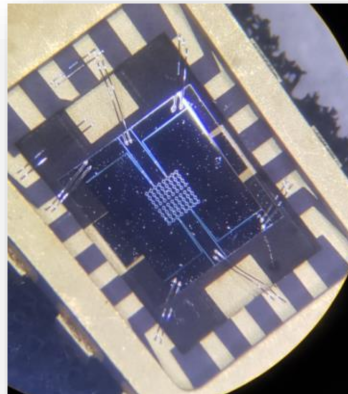


- external HV (5-20V)
- low noise, leakage current pA
- full CCE for p and C (+ others)
- Linear for various LET
- Radhard + compensation with HV
- Spectroscopic quality similar to Si
- **universal sensor**

SENSOR INTEGRATION

ceramic commercial DIL20



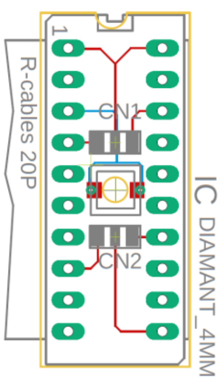


Universal ceramic DIL20 mounting:

- easy to exchange between various readouts for R&D
- sensors microbonding@SPEC

- needed custom modification (laser cut)

custom DIL20 pcb



Standard FR4 pcb for carrying on the sensor:

- cheap, easy to fabricate and modify ..
- system of pin connectors compatible with DIL20 socket

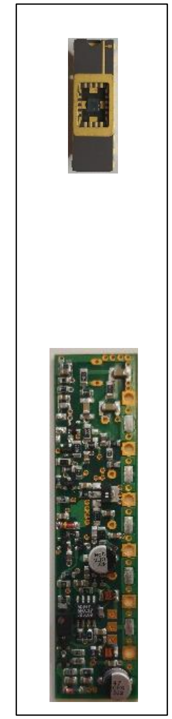
Ready for next sensors' mounting in 2020

READOUT - PREAMPS

pcb

pcb +
Amptek A250 (test board)

Pcb +
2-4 A250 (full integration 2020)



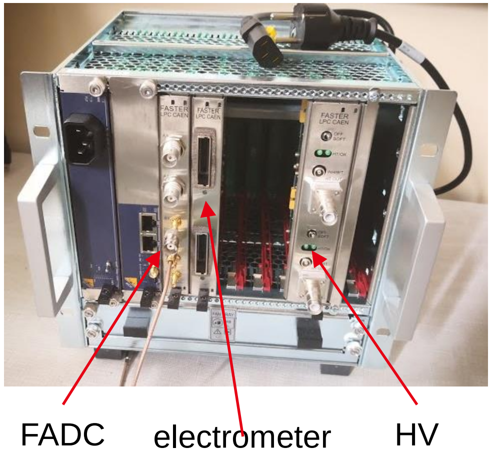
Diamond sensors are
compatible with microPlus probe
developed @ UoW
for Si microdosimeters

CENTRE FOR MEDICAL RADIATION PHYSICS

UNIVERSITY OF WOLLONGONG AUSTRALIA

READOUT AND DAQ

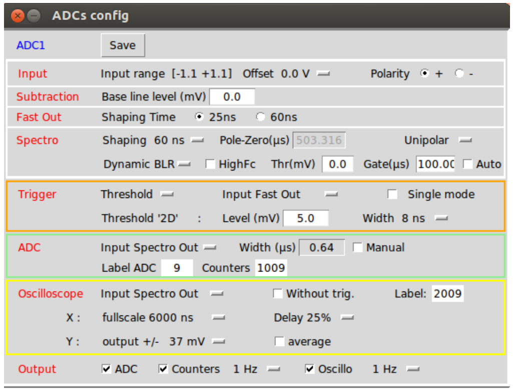
FASTER is a **modular** digital acquisition system based upon a synchronized tree model

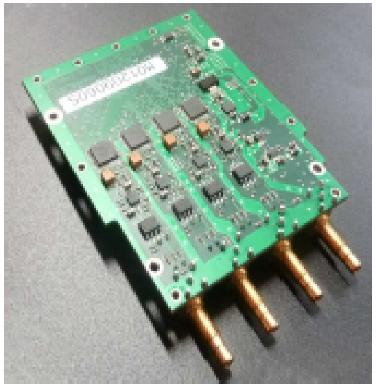


FASTER uses the following standards:

- UDP/IP protocol
- Ethernet gigabit connection
- NIM or microTCA crate
- VITA 57 daughter boards
- QDC, FADC, electrometer, HV

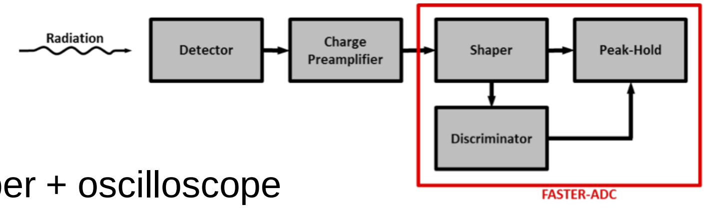
a firmware + software controler+ GUI





MOSAHR: Reduced usage but higher resolution, mainly for spectroscopic purposes

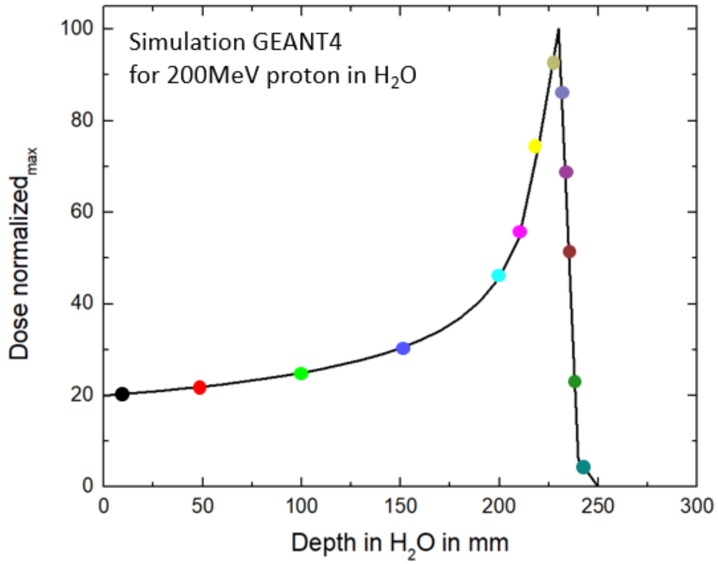
- 4 channels = 4 FADC (125 MHz, 14 Bits)
- ± 1 V, ± 2 V, ± 5 V, ± 10 V input dynamic range on 10 kΩ (switch selection)
- Noise: 1 lsbrms $\approx$ 130 μVrms (± 1 V range)
- Bandwidth = 25 MHz
- Crosstalk isolation > 97 DB

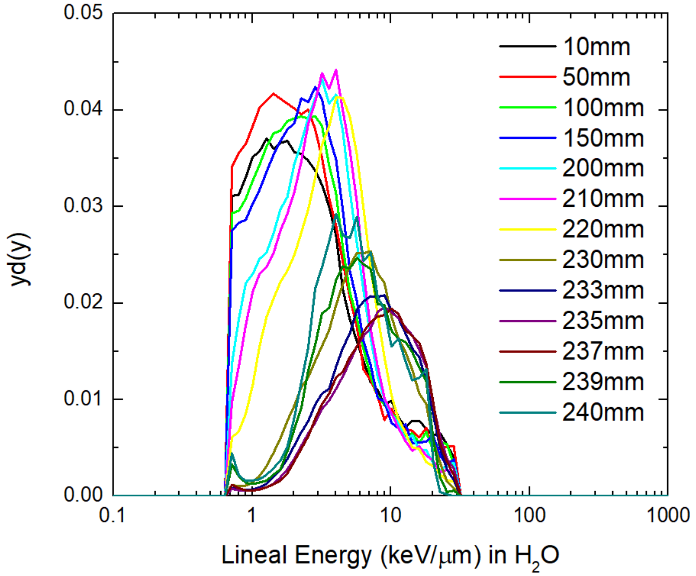


tunable high dynamic range + shaper + oscilloscope

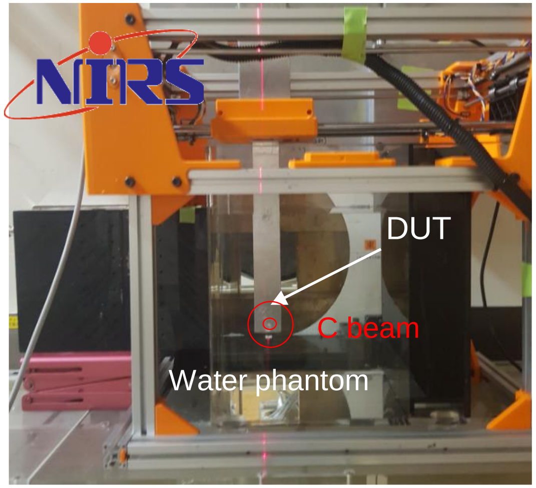
CLINICAL MEASUREMENTS AND SIMULATIONS

Proton Therapy Center @ IC-CPO Orsay
200 MeV proton beam
GR microdosimeter with analog amp and **FASTER readout**





CLINICAL MEASUREMENTS AND SIMULATIONS



HIMAC @ NIRS Chiba, Japan
290 MeV carbon, 230 MeV Si beams
GR microdosimeter
with Micro+probe readout

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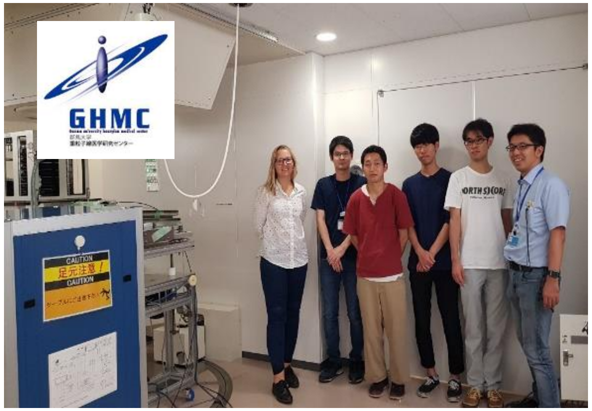
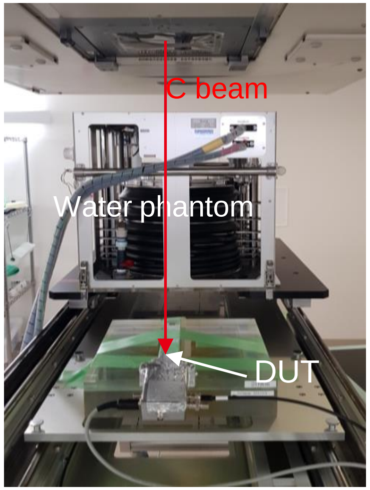


Gunma Heavy Ion Medical Center
@ Maebashi, Japan
290 MeV carbon beam
GR microdosimeter
with Micro+probe readout

群馬大学
GUNMA UNIVERSITY



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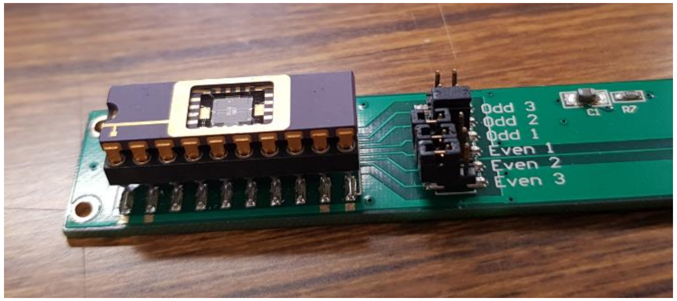
CLINICAL MEASUREMENTS AND SIMULATIONS



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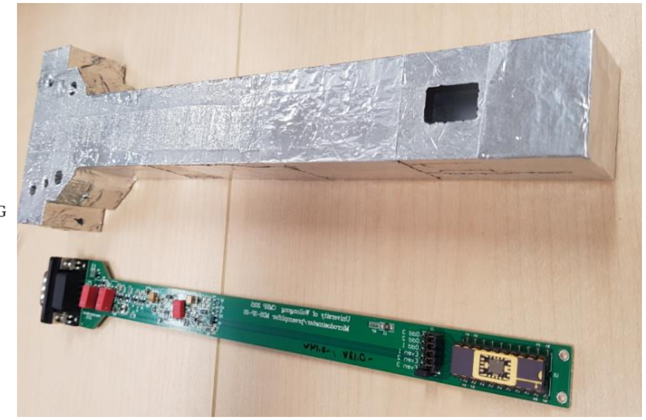
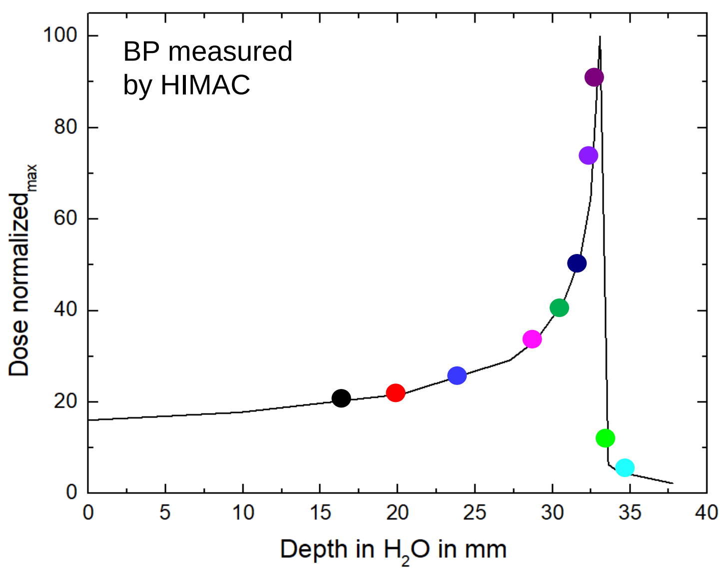
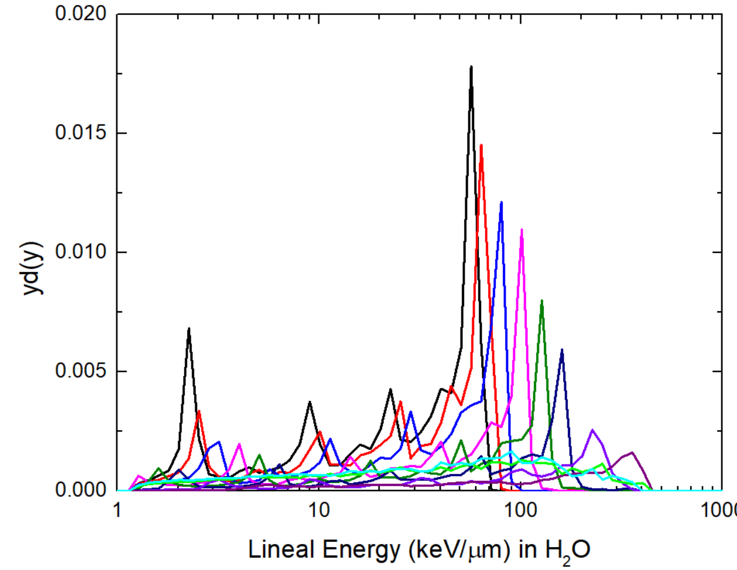


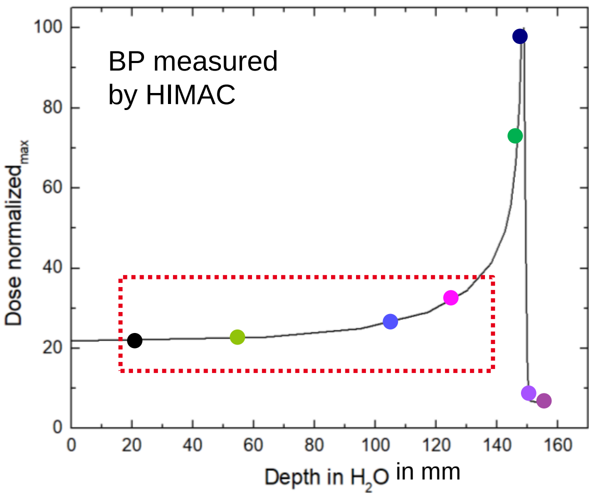
230 MeV Si

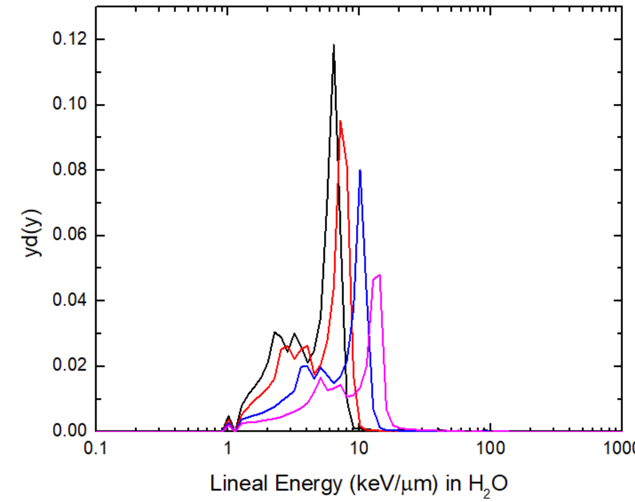




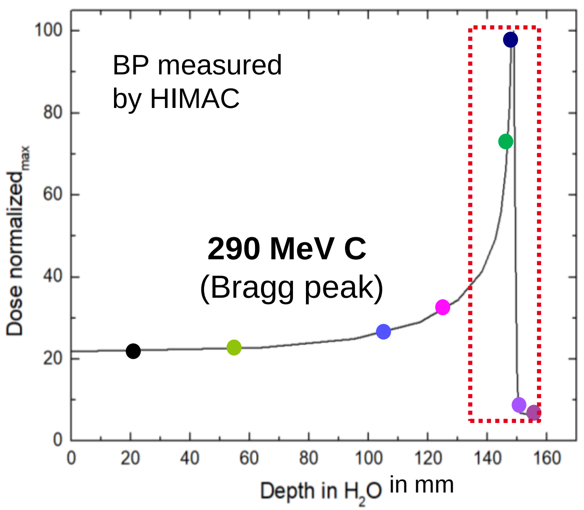
CLINICAL MEASUREMENTS AND SIMULATIONS

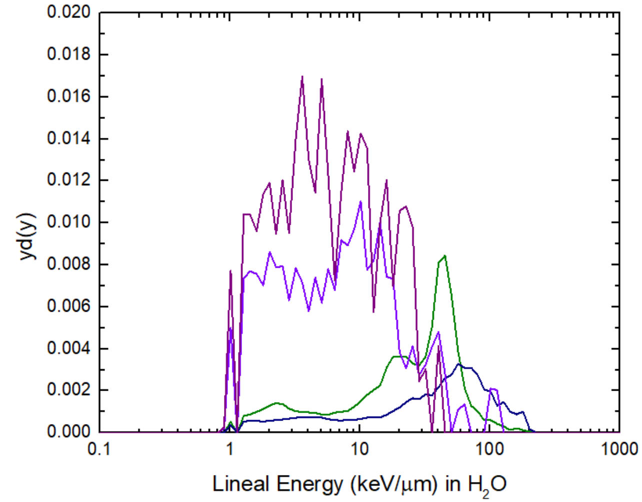
290 MeV C (plateau)





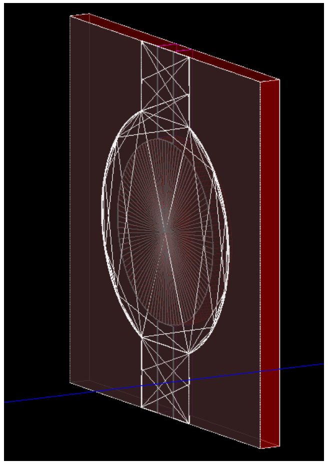
290 MeV C (BP + down stream)

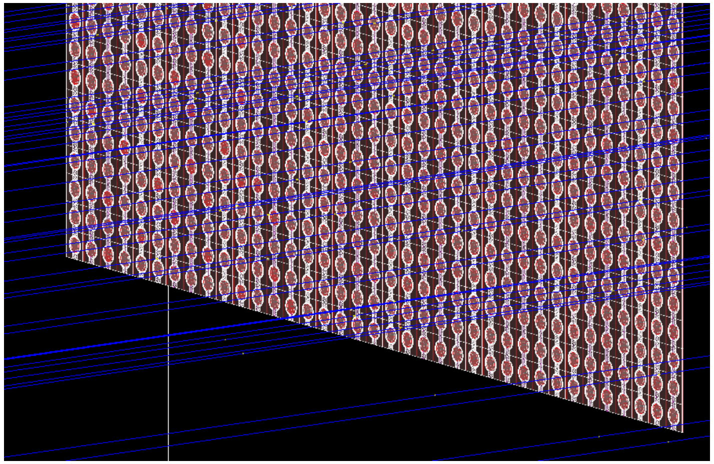


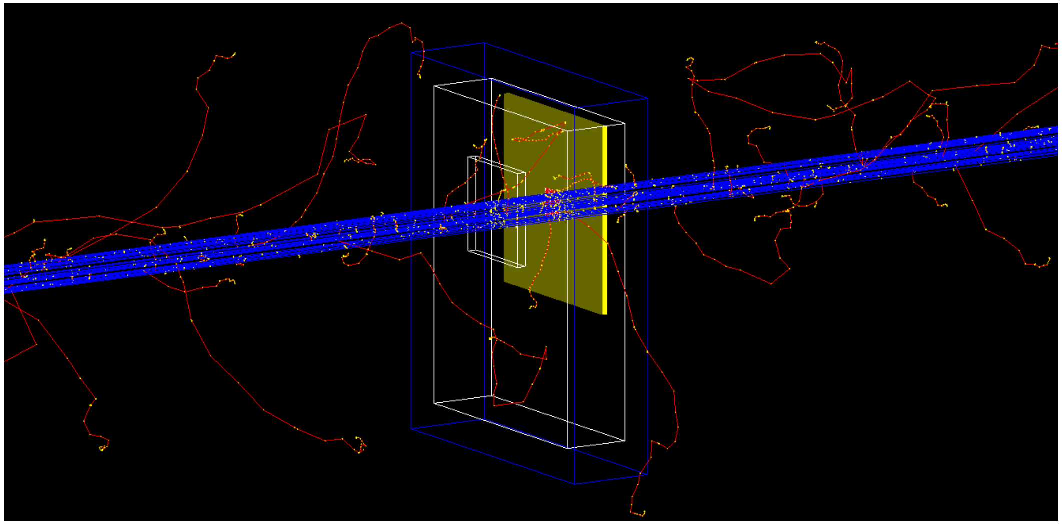


Benchmarking with MC Simulations

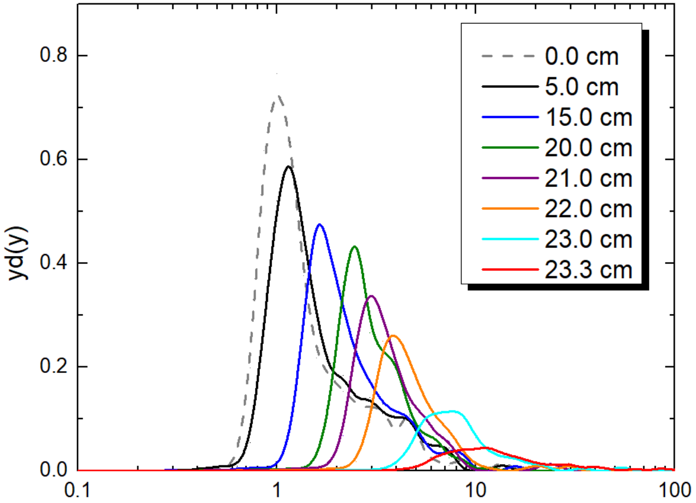
GEANT 4 (clinical beam sensor interaction)

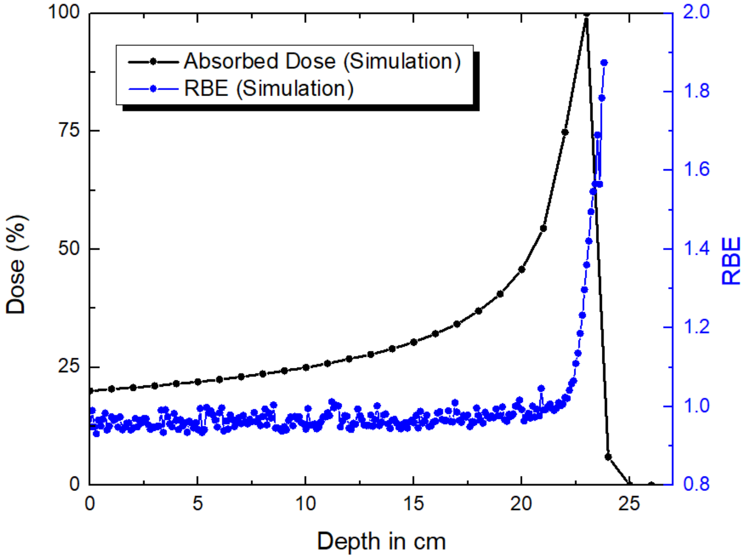






200 MeV p beam

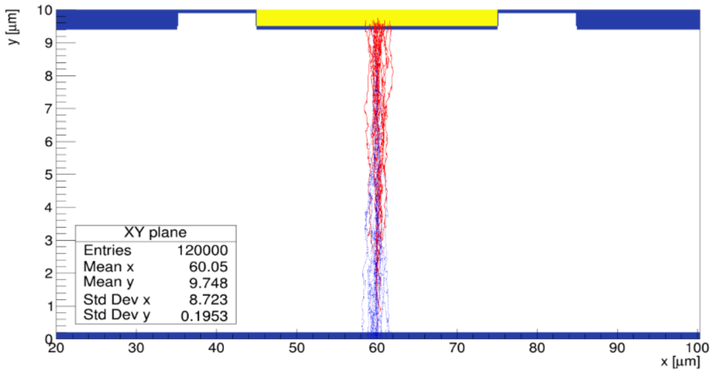


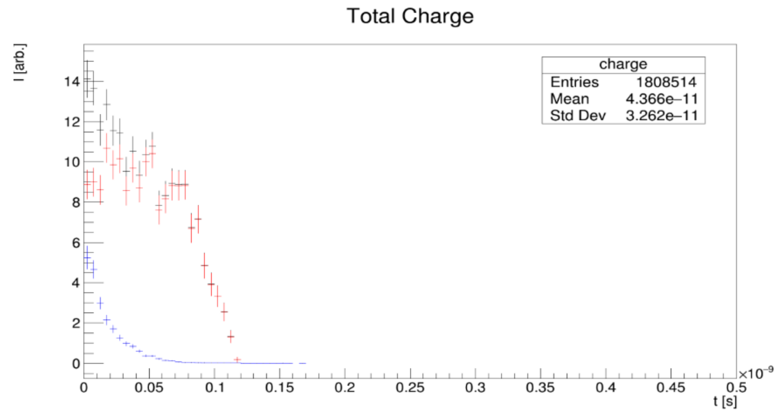


Benchmarking with MC Simulations

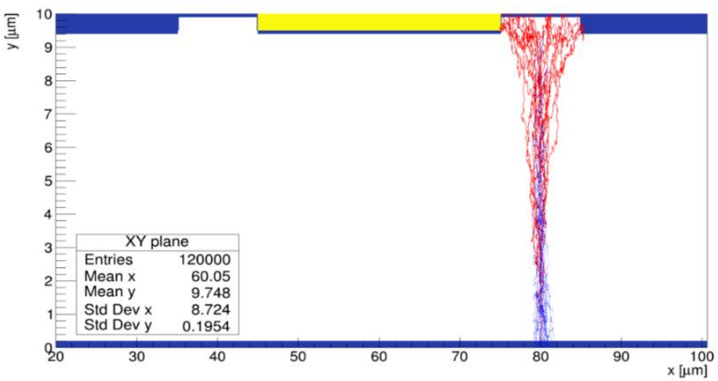
KDetSim (signal propagation at sensor level)

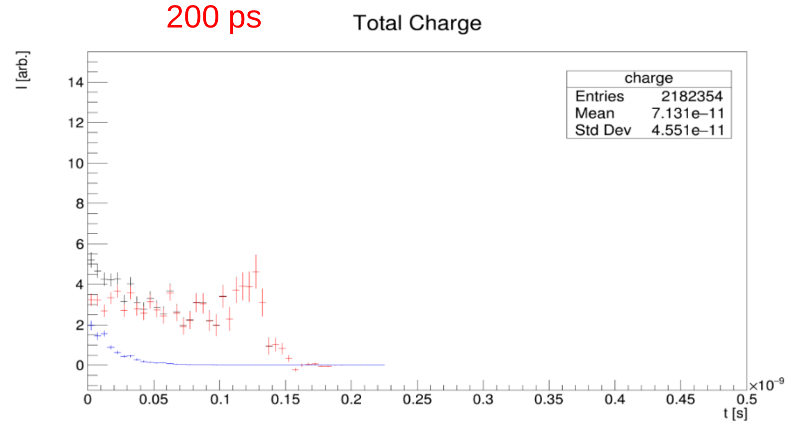
Charge sharing: 2D model Guard-Ring; 30 µm electrode, 10 µm gap, 10 µm thickness





200 ps





Freeware, based on ROOT 3D semiconductor detectors simulation software

http://kdetsim.org

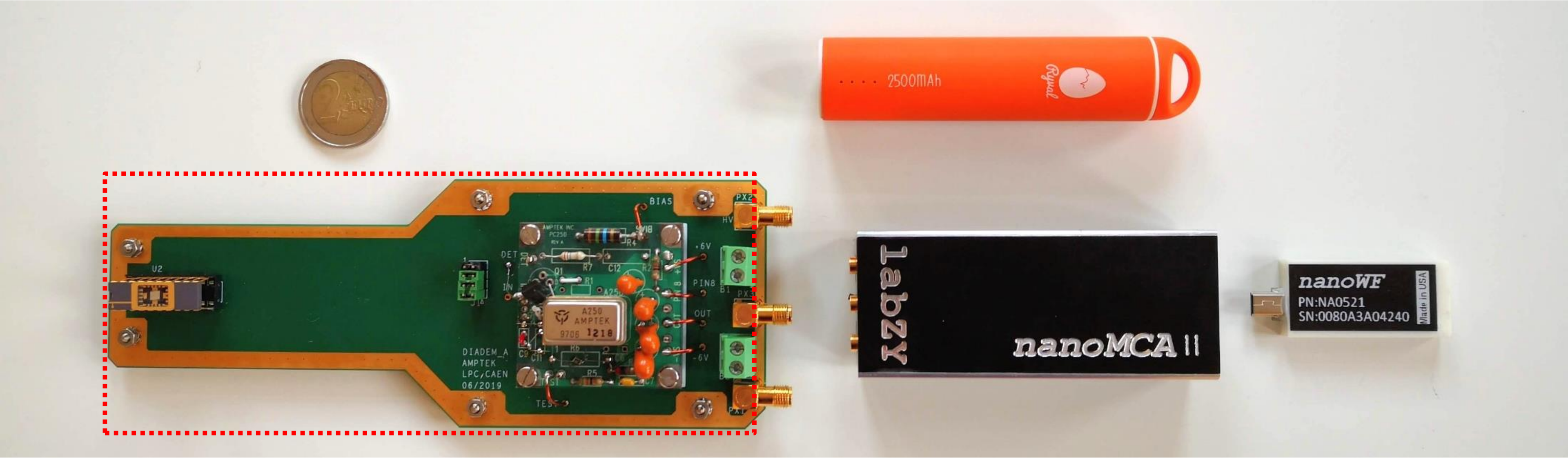
WHAT NEXT – SENSOR GO FULLY 3D

Content removed

NEXT STEPS – GO PORTABLE

One block PMMA water-proof packaging (here dashed line)

Custom made power bank:
Preamp, MCA+wifi powering
Detector bias (10-20V)



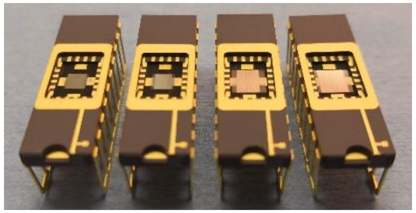
diamond sensor
DIL20 packaged

Pcb with integrated preamp. Here A250 amptek with its test board

MCA – signal shaping, amplification, digitalization, Spectra acquisition
digital pulser
1 channel

Wi-fi module for remote WLAN connection

Summary



- **scCVD diamond membranes have a great potential for solid-state microdosimetry**
  - p^+: Full CCE (proton) @ 0V, well-defined μSV
  - GR: Full CCE (for all tested ions) @ +/-20V, well-defined μSV
  - First Lineal Energy Measurements in Clinical Proton, Carbon Beams (promising)
  - Readout and system integration in progress
- **Issues to be addressed soon:**
  - Sensors: go fully 3D
  - On board dedicated electronics – fully portable system (sensor+amp+MCA+battery operation)
  - Clinical beams characterization

THANK YOU

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